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PROCESSING WITH AND WITHOUT LONG-TERM MEMORY MODIFICATION: ATTENTION, LEVEL OF PROCESSING AND WORD FREQUENCY

Walter Schneider and Arthur D. Fisk

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task; a graphic categorization task; a distracting digit search task while trying to remember presented words; or a distracting task while trying to ignore the simultaneous words. In the distracting digit search conditions frequency judgments of words were at or near chance. Distractor learning for the semantic and intentional conditions was better than for graphic orienting, which was better than chance. In the second experiment, subjects were trained for approximately 5,000 trials to develop an automatic categorization response. Subjects categorized distractor words as not being vehicle words 1 - 20 times and then performed a frequency judgment and forced choice recognition test. The results showed no evidence of a frequency estimation ability and little recognition memory for words semantically categorized twenty times. The data support the hypothesis of a close connection between controlled processing and LTM storage and little if any link between automatic processing and LTM storage. These results also suggest a reinterpretation of the Hasher and Zacks (1979) "automatic encoding concept." The relationship between LTM modification and attentional limitations of controlled processing is discussed. Methodological issues relating to assessing memory storage during automatic encoding are discussed.

Processing with and without Long-Term Memory Modification:

Attention, Level of Processing and Word Frequency

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Abstract

In this research we examine the relationships among long-term memory (LTM) modification, attentional allocation and type of processing. The experiments test the proposal from automatic/controlled processing theory (Schneider & Shiffrin, 1977) that the modification of LTM occurs only during controlled processing and that stimuli can be automatically processed with no resulting LTM effect. Subjects in the first experiment were exposed to words while performing an intentional learning task; a semantic categorization task; a graphic categorization task; a distracting digit search task while trying to remember presented words; or a distracting task while trying to ignore the simultaneous words. In the distracting digit search conditions frequency judgments of words were at or near chance. Distractor learning for the semantic and intentional conditions was better than the graphic orienting, which was better than chance. In the second experiment, subjects were trained for approximately 5,000 trials to develop an automatic categorization response. Subjects categorized distractor words as not being vehicle words 1 - 20 times and then performed a frequency judgment and forced choice recognition test. The results showed no evidence of a frequency estimation ability and little recognition memory for words semantically categorized twenty times. The data support the hypothesis of a close connection between controlled processing and LTM storage and little if any link between automatic processing and LTM storage. These results also suggest a reinterpretation of the Hasher & Zacks (1979) "automatic encoding concept". The relationship between LTM modification and attentional limitations of controlled processing are discussed. Methodological issues relating to assessing memory storage during automatic encoding are discussed.

Processing with and without Long-Term Memory Modification:

Attention, Level of Processing and Word Frequency

Walter Schneider & Arthur D. Fisk

A basic issue in memory research is the manner in which memory modification and information processing are interrelated. One basic question is whether humans can process information without any resulting long-term memory (LTM) storage. An affirmative answer suggests that LTM modification requires a special added stage or processing mode that is not needed for accurate performance on some types of tasks. Alternatively, if LTM modification occurs whenever information is activated in memory, then a memory modification mechanism is possibly inherent in the performance mechanism itself. In this paper we present evidence suggesting that, for well practiced automatic behavior (see below), the linkage between processing and memory modification is not direct and that processing without LTM modification can occur under certain conditions having appropriate experimental controls. We also suggest that there is a close linkage between attention capacity limitations and memory phenomena.

One proposal that accurate processing can occur without LTM storage comes from the dual process theories of information processing (see Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Dual process theories assume that performance results from the interaction between two qualitatively distinct forms of information processing (see Fisk & Schneider, in press; Schneider and Shiffrin, 1977; Shiffrin, Dumais, & Schneider, 1981; Shiffrin & Schneider, 1977). In this paper, these two forms of information processing will be referred to as controlled and automatic processing. The two-process approach to information processing has had a long history (James, 1890) and has received considerable interest in recent years (Hasher & Zacks, 1979; Laberge, 1973, 1976; Logan, 1978, 1979; Norman, 1976; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). <u>Controlled processing</u> is characterized as slow, serial, effortful, and capacity limited (see Shiffrin & Schneider, 1977). Controlled processes are under direct subject control, deal with novel or inconsistent information, and exhibit asymptotic performance with relatively little training. Shiffrin and Schneider (1977, p. 160) proposed that long-term memory modification was uniquely a function of controlled processing. On the other hand, <u>automatic processing</u> is characterized as fast, parallel, fairly effortless processing that is not limited by short-term memory capacity. Automatic processes allow performance of well developed skilled behaviors and require extensive training to develop. Automatic processing is predicted to activate nodes in memory but not to modify long-term memory directly.

The proposed distinctive functions of automatic and controlled processing suggest that memory modification and information processing are not necessarily linked. The dual process proposal predicts a linkage between the amount and type of controlled processing and LTM storage. Accordingly, it predicts that subjects can be trained to automatically process information (e.g., perform a well learned consistent semantic categorization) accurately without any LTM storage.

One alternative view to that presented above is that attention is not needed for *long-term memory storage*. Kellogg (1980) has proposed that learning can occur without conscious attention. In his paradigm, subjects perform a primary task (e.g., multiplying numbers) while they "look at the faces, but avoid consciously thinking about them" (Kellogg, 1980, p. 383). Kellogg finds evidence for long-term memory modification of the non-explicitly processed information. However it is quite possible that subjects in these procedures did indeed attend to additional stimuli. For example, subjects had 9.3 sec to look at a picture, and the workload of the primary task was not always sufficient to fully occupy attentional resources (e.g., *subjects were told that if they* successfully performed all the additions, they were to "mentally check their work", p. 383).

Still a third view is that relevant cues must be attended to, but once attended to -- no *additional processing is necessary for* learning (at least for certain types of information). This proposal comes under various names: learning without awareness (see Brewer, 1974, for a discussion of this topic), implicit learning (Reber, Lassin, Lewis, & Cantor, 1980), unconscious learning (Silver, Saltz, & Modigliani, 1970), and learning without effort (Hasher & Zacks, 1979). *The problem with this* position is in specifying the amount of attention given to any specific stimulus.

Hasher and Zacks (1979) provide an explicit model which states that once stimuli are attended certain attributes are encoded without additional processing. Hasher and Zacks (1979) argue that the ability to estimate the frequency of an item's occurrence is accomplished via an automatic encoding process. They define "automatic encoding" somewhat differently than the definition given above. *They define automatic encoding operations as ones that:* "drain minimal energy from ... [an] attentional mechanism ... [do] not interfere with other ongoing cognitive activities ... function at a constant level under all circumstances ... occur without intention, and do not benefit from practice [at least for well practiced automatic behaviors]" (Hasher & Zacks, 1979, p. 356). *They predict that encoding of frequency information* "functions at a constant level in all circumstances" for the processing of attended stimuli. Hasher & Zacks state that for "an automatically encoded attribute to enter long-term memory the person must be attending to the input" (p. 358) and that this encoding does not consume any limited capacity. With respect to the *definitions in the current paper, the* attending requirement suggests controlled processing. On the other hand, the lack of a capacity utilization suggests automatic processing. From the automatic/control processing perspective we might rephrase the Hasher and Zacks position as once stimuli receive some minimal control processing (i.e., are attended) there is no effect of the nature and amount of control processing.

The Hasher and Zacks (1979) empirical prediction that frequency encoding is insensitive to strategy manipulations *is at odds with the prediction that* LTM storage is a function of the amount and nature of controlled processing. Consistent with the Hasher and Zacks position, frequency encoding seems insensitive to the effects of strategies, individual differences, and practice effects (Hasher & Zacks, 1979; Zacks, Hasher, & Sanft, 1982). In the procedure used by Hasher and Zacks (1979, p. 371), *subjects are presented words* 1, 2, 3,

or 4 times. The words are presented at a 4-sec rate. Subsequent to presentation of the word list, the subjects are given a test sheet and asked to judge the frequency of occurrence of each word. Subjects were either "uninformed" or "informed" in regard to the subsequent frequency test. The uninformed group was told "pay close attention [to the word list] because after you see the list your memory will be tested." The informed group was given the above instructions and told that the memory task would be concerned with the frequency of the words' occurrences. *In their studies, Hasher and Zacks* (1979) found that the ability to estimate frequency was not dependent on age, intention (informed versus uninformed), practice, or emotional state.

From the automatic/controlled processing perspective, the insensitivity of frequency *estimation performance can be interpreted* as resulting from an early asymptote of frequency information. Since stimuli are presented for long durations (e.g., 4 sec) and subjects are told to encode the words for later recall, subjects would be expected to control process each word. *If one assumes* that there is little marginal benefit for frequency information of controlled processing *beyond a short period* (e.g., 1 sec), the insensitivity of frequency encoded data to subject strategies would be expected. Crucial tests of "automatic" frequency encoding would require using a paradigm that a) reduced available controlled processing time and/or resources and b) insured that performance was measured in a range where there was still a performance benefit from additional processing time or resources. From the Hasher and Zacks position, changing strategies should have no effect on frequency encoding. From our position, if both the nature and amount of controlled processing influence the amount and form of *long-term memory modification, strategies* should make a difference.

A number of experiments that assess memory modification when controlled processing resources are allocated to another task show little evidence of LTM storage (see Underwood, 1976). Moray (1959) *presented* a list of seven words to the subject's unattended ear 35 times during a shadowing task. He found recognition of those unattended items to be at chance. In contrast, words presented once in the attended ear were well recognized. *Gleitman and Jonides* (1976) found that items used as distractors in a reaction time experiment where *later recognized at chance* in a consistently mapped (see below) reaction time task. Gordon (1968) showed that a set of four distractors were recognized at a level near chance even after 10 days of practice. Grabol (1971) had subjects perform a visual search for proper names. After subjects had searched through a set of 50 names 540 times, they could recall only about 10% of the words.

Wolford and Morrison (1980) investigated phenomena associated with selective attention using a task that they refer to as *a visual analog* to auditory selective attention paradigms. In their *experiments*, the subjects (in the condition of interest) were to attend to two single digits and ignore words *presented between the digits*. The subjects judged whether the digits were both odd or even (same parity) or of different parity (i.e., one odd and one even digit). In this condition, the subjects reported the occurrence of their own names but their memory for the other *unattended words* was very poor.

There are a number of potential problems with such studies in regard to showing no memory trace effects of information in unattended channels. First, there is frequently no indication of the sensitivity of the measure of memory modification. In general, the experiments do not show how sensitive the dependent measures are to attended information (see Kellogg, 1980).[1] This is particularly crucial in experiments where subjects received substantial exposure to the task and related materials before the "to be remembered materials" were presented (e.g., Gleitman & Jonides, 1976; Gordon, 1968; Grabol, 1971; Wolford & Morrison, 1980). We do not know, for example, how well subjects would recognize material they are attending to in a well practiced but potentially boring task. Second, there is the problem of the efficiency of encoding the stimulus material. Gleitman and Jonides used digits and letters for stimuli while the distractors used by Gordon were patterns of four dots. The inability to efficiently encode the distractor stimuli may account for the results. The third problem is that there is no indication of the extent to which the unattended material is actually processed. If the unattended materials are just processed to some early featural level sufficient to be discarded (e.g., evaluating the location of input), then there might not be sufficient processing of semantic features to be detected by the measurement precision of a word recognition test.

There are also potential problems associated with conducting and interpreting studies examining recognition of presumably unattended material. If one uses a very sensitive measure for LTM storage, one might be able to detect subjects attending to a stimulus for a brief period. For example, Potter (1976) has shown significant recognition of pictures presented for only 125 msec. To support the claim of unattended learning we must be able to detect occasional short (e.g., 125 msec) switches of attention. To illustrate, in the Kellogg (1980) study subjects were presented faces for 9.3 sec. If on every trial subjects attended to the faces for 125 msec, their time attending to the multiplication task would drop only 1.3%. It is unlikely that any dual task measure could reliably identify a 1.3% drop in performance.[2]

It is difficult to have subjects fully attend to any task for even modest periods of time (e.g., five minutes) without attentional drift (e.g., see vigilance literature, Fisk & Schneider, 1981). Note also that most dual-task paradigms also get such drift, regardless of instructions to the contrary. Hence, even single task controls may include a significant percentage of time sharing (e.g., attempts by the subject to predict the next stimulus or identify the purpose of the experiment). To conclusively measure "pure automatic encoding" there must be major advances in both the measurement of attentional drift and methods of motivating subjects to maintain full attention on the primary task. Until such advances are achieved, we suggest that experiments assessing automatic encoding should provide controls which allow estimation of how much time sharing would be necessary to predict any LTM storage resulting from short attentional drifts. The experiment should be run to minimize attentional drift while assessing memory with the most sensitive techniques available. Then the conclusions should describe how much learning and attentional drift occurred and estimate how much drift would predict the observed learning.

The following experiments test the predictions relating automatic and controlled processing to memory modification while attempting to deal with the methodological problems presented above. Experiment 1 assessed the ability to estimate the frequency of occurrence of words in five "learning" situations. These conditions differed in the amount and form of control processing that words received. Subjects were asked to estimate the frequency of occurrence of words after engaging in: a) an intentional learning task, b) an incidental learning task with either a semantic or orthographic orienting task (see Hyde and Jenkins, 1973, for a review of orienting tasks), or c) two unattended learning conditions where subjects detected digits presented around foveally displayed words. (The words were presented foveally.) In these latter two conditions the subjects were to perform the digit task and either "look at" the words or ignore the words. The discussion of the first experiment will evaluate how LTM storage varies with the amount and nature of control processing. Experiment 2 was conducted to establish the degree to which the automatically processed stimuli modify memory. Subjects were first trained to detect words automatically from a semantic category. Then controlled processing resources were consumed by requiring subjects to perform a digit search task (as a primary task) concurrently with the semantic search task. The discussion of the second experiment will evaluate whether accurate processing can occur without LTM storage.

Experiment 1

In this experiment we examine LTM storage under various "learning" situations by measuring subjects' ability to estimate the frequency of occurrence of words presented under different orienting conditions. The frequency estimation task was chosen because it provides a sensitive measure of LTM storage (e.g., Hasher and Zacks, 1979; Howell, 1973). In addition, the frequency estimation paradigm is appropriate for multiple stimulus presentations. If, as Shiffrin and Schneider (1977) proposed, controlled processing is required for LTM storage, an item presented 10 or even 20 times should not be remembered (i.e., frequency estimation should be poor) when controlled processing has been completely diverted from processing of the item. This type of design also provides for an estimate of the sensitivity of our memory measure (i.e., we can determine how many repetitions are required before performance is above chance).

We varied the presence and form of controlled processing. The presence of controlled processing was manipulated by either having subjects attend directly to the word on each display or having them search for two digits on each display. The form of controlled processing was varied by requiring those subjects who were directly attending to the words to perform one of three orienting tasks. After the search task, subjects judged the frequency of distractor words presented during the search task. It was predicted that (task appropriate) controlled processing should yield better memory (i.e., frequency estimation) than controlled processing that is not task appropriate. Semantic processing or intentional encoding was expected to store semantic features which would result in accurate word recognition performance (e.g., see Morris, Bransford, & Franks, 1977). Graphic processing in letter search within the

displayed words or graphic processing of the digits around the words was expected to result in little encoding of the word features and hence was expected to show poor word recognition. These predictions contrast with the Hasher & Zacks (1979) prediction of frequency estimation being insensitive to strategy variations.

<u>Subjects</u>. Ninety students from the introductory psychology subject pool at the University of Illinois participated in this experiment. Eighteen subjects participated in each experimental condition with order of assignment being random. Subjects were run in groups of three or less. All subjects reported English as their native language and had normal or corrected-to-normal vision.

<u>Equipment</u>. The experiment was computer controlled. The computer was programmed to present the appropriate stimuli, collect responses, and control timing of the display presentation. The stimuli were presented on Tektronix model 604 and 620 cathode ray scopes with P-31 phosphors.

<u>Design</u>. There were five experimental conditions: (see Figure 1) 1) <u>Intentional Learning</u> -- subjects were instructed about the subsequent frequency estimation task and were required to push a response button when they detected a word representing the name of a vehicle (a semantic orienting task); 2) <u>Semantic Orienting</u> -- incidental learning condition in which subjects were instructed to respond whenever they detected a word representing the name of a vehicle; 3) <u>Graphic Orienting</u> -- incidental learning in which subjects were required to respond to any word containing a letter "G"; 4) <u>Look</u> -- intentional learning in which subjects were required to search for the presence of one of two digits in displays containing two digits and to look at words presented in the fovea. Subjects in the Look condition were told that the experiment was designed to "see how much could be remembered when something more important was happening." These subjects were informed that the most important task was the digit detection task. 5) The last condition, the <u>Ignore</u> group -- incidental learning in which subjects performed the digit detection task and were told to ignore the words because the words were inserted to distract them from the digit detection task.

Insert Figure 1 about here

<u>Stimuli</u>. The digits used in the experiment were 2, 3, 5, 6, 7, 8, and 9. For each display sequence, two digits were randomly chosen as memory set items (ignored by those not performing the digit detection task) with the remaining digits used as distractors. All words were three letters in length and were chosen from 16 different taxonomic categories from the Battig and Montague (1969) norms. There were 35 distractor words chosen from 16 categories excluding vehicle. In the other conditions, there were four target words from the vehicle category. In the Graphic condition, there were four target words chosen from four categories and limited to words containing a "G".

The frequency of occurrence for the non-target words was 1, 5, 10, and 20 with 11, 13, 8, and 3 words used for each frequency of occurrence, respectively. There were four target words each being presented either 2, 10, 20, or 40 times. (Note, subjects in the digit detection conditions were presented the same target words as the Semantic Orienting conditions even though they did not respond to them.)

The digit and the letters (making up the words) were constructed by placing dots on a rectangular grid 32 dots wide by 48 dots high. The characters subtended .58 degrees in height and .52 degrees in width. The refresh rate of the dots making up the stimuli was 10 msec.

At the end of the experiment, subjects were given a frequency estimation task. They were presented with a sheet of paper containing 63 words; 24 of the words were new words never presented during the display sequences. The remaining words were the 35 distractor words and four target words presented as described above. The 24 new words were three letter words chosen from the same 16 taxonomic categories as the presented words. Word order for the frequency estimation task was permuted to give four different word orders.

<u>Procedure</u>. Subjects were first given instructions about the task. Next were presented 30 trials which contained 12 words and 48 digits. Following the stimulus presentation, subjects completed a two-minute math test. Finally, the subjects were given a frequency estimation task and then debriefed.

Figure 2 illustrates the display sequence. All distractor displays were the same across all subjects and conditions. For a given display sequence the subjects were first presented with a two digit number (the memory set for the digit detection task), followed after 3 sec by a fixation dot. The fixation dot remained on the screen for 500 msec and was followed by the digit/word displays. The digit/word displays consisted of a series of "frames", where each frame contained four elements positioned to form a square around a three letter word. Each digit display contained two digits on one diagonal of the square and two random dot patterns on the other diagonal. The diagonal containing digits (or masks) alternated on each digit display. Each digit display remained on for 300 msec. Each three letter word was displayed for 600 msec (i.e., for two digit frames), allowing 12 words to be displayed for each display sequence which consisted of 24 total frames. Word display order was randomly determined with the restrictions that the same word could not appear on two successive frames and that the frequency of occurrence constraints (see above) were not violated. In order to allow fixation, a 600 msec display of X's in all digit and word display positions was presented after the fixation dot and prior to the digit/word displays. Following each display sequence (i.e., a complete series of frames), a 300 msec display of X's was presented to mask out digits and words.

Insert Figure 2 about here

The two digit memory set display remained on for 20 sec for the first three trials to allow the experimenter time to re-explain the instructions if necessary. Thereafter the memory set was presented for three sec. With the exception of the first three trials, the display time was 11.1 sec for each sequence. The experiment consisted of 30 trials, the first five and last five trials were considered buffer sequences and were thus not analyzed. None of the words in the buffer sequences were tested during the frequency estimation task. Some of the words in the buffer sequences were digit names. The digit names were presented to facilitate belief in the cover story that we were assessing digit detection accuracy while distracting words were presented.

In the digit detection condition, the subjects searched for target digits (i.e., either of the two memory set digits) within the four element display that surrounded the words. The digit search was variably mapped (i.e., memory set digits changed from display sequence to display sequence, and were randomly sampled from the same digit set). Such a variably mapped search task requires controlled processes even with extended practice (see Schneider & Shiffrin, 1977). The task of comparing two memory digits to four display digits every 300 msec was difficult enough that no subject would be expected to perform at ceiling. Thus, if subjects attempted to perform maximally on the digit task there would be little or no controlled processing resources available for processing the words. There were three target items presented during each display sequence (subjects were told this fact and were encouraged to try to get all three digit targets on each trial). The first target item could occur on frames 3 to 6, the second on frames 10 to 15 depending on the first target's location, and the third target occurred in frames 21 to 23. Subjects in the digit detection conditions responded by pushing a button on their response box which corresponded to the target's display position (e.g., if a target occurred in the upper right display location of the square, the subject was to push the upper right response button.) Upon the target's occurrence, subjects were allowed 1.8 sec to respond in order to have the response recorded as a hit. All responses not occurring within this time interval were considered false alarms.

Subjects in the Semantic Orienting, Graphic Orienting, and Intentional Learning conditions were to ignore the digits and respond when an appropriate target word occurred by pushing one response button. Similar to the digit detection task, there were three target words per display sequence. The display location (i.e., frame number) was determined as in the digit detection task except that target item location was required to begin with an odd frame.

The total time for all display sequences was 6.4 minutes. Subsequent to the display sequence was a two-minute math test (a distraction task that served to clear short-term memory) followed by the frequency estimation task. Subjects were allowed up to 10 minutes for the frequency estimation task. When subjects were given the frequency estimation task they were told that some of the words on the sheet had never been presented and none of the words had been presented more than 50 times. The subjects were instructed to make their best estimate of the number of times they saw each item.

Evaluation of long-term memory change. Subjects performed the frequency estimation task on the 35 presented words and 24 new words. In addition to the

frequency estimation measure, the ability to distinguish presented from non-presented words was estimated. If a subject gave a non-zero value for a word actually presented, it was scored as a hit; non-zero values given for nonpresented words were scored as false alarms. These data (individual subjects' scores) were then converted to estimated detection accuracies.

Results

Search detection accuracy. Subjects were able to accurately perform their respective search tasks. The word search hit and false alarm rates were 97.7% and 5.0% for the Semantic condition, 93.3% and 5.2% for the Intentional condition, and 95.9% and .8% for the Graphic condition. The digit search hit and false alarm rate were 71.0% and 1.6% in the Ignore condition and 69.0% and 3.5% in the Look condition. The digit detection data indicate subjects were not at ceiling and hence, were assumed to be devoting nearly all their controlled processing to the digit task.

Frequency estimation. Figure 3 presents the subjects' performance in estimating the frequency of occurrence of the words. The median reported frequencies are provided. The means were unstable since individual subjects would occasionally guess a very high frequency of occurrence for a word (e.g., 50). As can be seen in Figure 3, if subjects performed the digit detection task, they were not able to estimate the frequency at which the words occurred. In the Look condition, subjects were unable to estimate word frequency even when they were given orientation instructions which suggested they should remember the words. The subjects who processed the words (i.e., Intentional, Semantic, and Graphic conditions), did show an ability to estimate word frequency.

Insert Figure 3 about here

The correlations between the subjects' estimated frequency of the occurrence of each word and the actual frequency of occurrence was .01, .14, .29, .63, and .64 for the Ignore, Look, Graphic Orienting, Semantic Orienting, and Intentional Learning conditions, respectively. The correlation between the actual and reported frequency of occurrence, referred to by Flexser and Bower (1975) as the discrimination coefficient, provides a relatively unbiased measure of the subjects' ability to distinguish one frequency from another (see Flexser & Bower, 1975, pp. 322-323). An analysis of variance (on the z transformed correlations) showed that the main effect of conditions was significant [$F(4,85) = 46.41$]. The correlations in the Ignore and Look conditions were at chance; the other conditions were significantly above chance ($p < .05$). Newman-Keuls post hoc analyses (with criterion significance at $p < .05$) indicated that the Intentional Learning and Semantic Orienting conditions did not significantly differ. Also, the Ignore and Look conditions did not significantly differ. All other comparisons were statistically significant.

Recognition performance. Table 1 presents the subjects' ability to distinguish the old from the new words. Discrimination sensitivity is presented as a function of the number of times words were presented. To estimate

sensitivity, a hit was recorded if a non-zero frequency was given for an old word and similarly, a false alarm was recorded if a non-zero frequency was given to a new word.

Insert Table 1 about here

Multiple pairwise t-tests were carried out to determine in which conditions hits exceeded false alarms. We used very liberal (from a Type I error perspective) statistical tests to reduce the chance of a Type II error. A finding of non-significant recognition with these procedures provides strong evidence indicating a lack of LTM storage. Table 1 presents the various significance levels so readers may set their own criterion. All tests were one-tailed. Note, when performing five tests (within each orienting condition) with a significance level of .05, the probability of at least one score exceeding that level by chance is .23. Table 1 also provides estimates of within subject corrected recognition accuracy scores [corrected accuracy = (Hits - False alarms)/(1-False alarms)]. Comparing corrected accuracy with zero produced essentially the same pattern of significance scores.

Examining the recognition accuracy averaged across all of the distractors regardless of presentation frequency, we find accuracies of -.002, .11, .44, .66, and .65 for the Ignore, Look, Semantic and Intentional conditions respectively. Accuracy was significantly above chance (p < .001) in all conditions except the Ignore condition which was at chance (p = 1.0).

In the Look condition (i.e., digit search with instructions to look at the words) recognition accuracy was reliable (.11). It appears however that at least five repetitions of a word must occur before the present measures could reliably identify a better than chance recognition level.

In the Graphic, Semantic, and Intentional conditions, the present recognition measures could reliably detect (p < .001) a single occurrence (i.e., frequency 1) of a distractor presented once for .6 sec. Recognition improved with repetitions. As with the frequency estimation data, Semantic and Intentional conditions showed equivalent recognition performance (accuracies of .66 and .65) which was better than the Graphic condition (accuracy .44).

Discussion

One of the objectives of this experiment was to assess the sensitivity of our memory test. The Intentional condition provides an estimate of the recognition performance of intentionally processing a word while semantically categorizing it. In the Intentional condition a word presented once for .6 sec in a list of 360 words and then followed by a two-minute math test resulted in a .37 corrected recognition probability. This provided a significant recognition level (p < .001). Even in the Graphic condition without any indication of a memory test, a single presentation of a word resulted in a .24 recognition probability.

Having an estimate for the recognition memory resulting from processing a word once, we can predict the expected recognition performance as subjects spend small periods of time processing the words. We assume that the proportion of time allocated to the word task determines the proportion of words processed and that the learning per processed word is equal to the observed data in the Intentional or Semantic conditions. For example, if a subject spends 10% of the time intentionally processing the words, the expected total recognition probability would be .18 (see Appendix for estimation details). If we assume *the subject intentionally processes 5% of the words, the expected recognition* performance would be .10. Similarly, if we assume the subject spent 10% and 5% of the time processing the words at the orthographic level the expected recognition probabilities would be .11 and .06 respectively. These predictions are based on a very simple model of resource trade-off and are likely to underestimate true recognition performance.[5]

The Ignore condition data provide no evidence of recognition for unattended words. A word presented a total of 12 sec over 20 separate displays was recognized at chance. Subjects in the Ignore condition did try to guess the word frequency averaging a 10% false alarm rate. Therefore this poor recognition is unlikely to be due to demand characteristics or lack of sensitivity in the memory test. The significant recognition performance after a single presentation of a word in the Graphic condition illustrates both the sensitivity of the memory measure and that subjects were willing to accurately report the frequency data when the recognition test was unexpected. The frequency 10 recognition performance in the Ignore condition (.068) was statistically significant with very liberal statistical procedures (i.e., executing five independent one tailed t-tests with p = .05 without correcting for multiple tests). In the Ignore condition the probability that at least one *of the five t-tests would exceed the liberal* .05 level is .23 (given that there is no learning). If we correct for multiple tests, this condition would not be significant at the .05 level. We discount the .068 recognition level as significant because: 1) the lack of overall significance in the accuracy summed over all the words; 2) the high probability of a Type I error (i.e., 23%); and 3) the possibility that subjects might have a response bias toward one of the eight frequency ten words.

The lack of recognition in the Ignore condition is somewhat surprising given the likelihood that some of the subjects may have been suspicious that there would be a later test on the words. The subjects were from a subject pool of students taking an undergraduate psychology course. These subjects are generally quite suspicious about deception. It is quite likely that some subjects would examine the words because of a combination of curiosity, unwillingness to put the full effort into the difficult digit search task or a desire not to be caught by deception. With the sensitivity of the measures involved, if a third of the subjects allocated only 10% of their resources to processing the words, the predicted recognition accuracy would have been .06 which would have been significantly different from zero (p < .01).

We feel that a good cover story in the Ignore condition was critical to motivate subjects not to attend to the words. In pilot testing, laboratory staff participated in the Ignore condition. Although the staff subjects tried

not to attend to the words, all showed significant recognition. The knowledge that this experiment would examine memory resulted in the staff subjects dividing resources even though they attempted to allocate all their resources to the digit task. We feel that the cover story we used was critical to obtain the "no learning" results. Our subjects were told the purpose of the experiment was to determine how well they could perform digit search while distracting words were presented. During the first five trials the words presented included digit names. These words did appear to distract the subjects and subjects made an effort to ignore the words.

<u>Lack of long-term storage without attention</u>. The present lack of significant recognition in the Ignore condition is <u>incompatible</u> with the proposal that long-term storage occurs without conscious attention (Kellogg, 1980). *With sensitive recognition measures we found no evidence of long-term storage.* There are many procedural differences between our experiments and those of Kellogg (1980). Kellogg used picture stimuli; presented the pictures for 9.3 sec while subjects carried out a multiplication task; indicated that the subjects should visually register the stimuli (cf. p. 383); and used a recognition confidence rating procedure. We feel there are four critical differences between our procedures and his. First, we used a more continuously resource consumptive task (i.e., requiring four comparisons every .3 sec). Second, our subjects were provided more direct feedback to encourage allocating attention to the primary task. Our subjects knew they were not detecting the three targets on every sequence and hence always knew they were performing below expected performance. In contrast, Kellogg's subjects were apparently not given feedback on the multiplication task and occasionally finished the digit task before the end of the 9.3 sec period. Third, we had a more appropriate cover story. Our subjects felt they would perform best if they ignored the words. And fourth, we presented buffer trials (60 words) so that the word presentation was no longer novel when the critical words were presented. Wolford and Morrison (1980) have found that subjects attend to words during the early part of an experiment. In the Kellogg study it seems unlikely that subjects did not examine at least the first few pictures presented.

<u>Learning with a small division of resources</u>. The Look condition illustrates how a small, not statistically significant, reduction in resources for the digit task can result in significant recognition performance. The corrected <u>digit detection</u> accuracy in the Look condition was .684 and in the Ignore condition it was .717. The standard error of measurement is .031, thus precluding any reliable assessment of trade-off between the Look and Ignore condition. However, it is a useful illustration to estimate what the expected recognition would be if subjects divide resources at the observed levels. Assuming accuracy is a linear function of resources, the data suggest that the Look subjects were expending 95% of the resources in the digit task relative to the Ignore subjects. This would suggest that subjects could devote 5% of their resources to examining the words. Assuming subjects used these resources for semantic or intentional processing of the words, that would result in an expected (see Appendix) recognition accuracy of .10 compared to an observed accuracy of .11.[4] *Although the present resource trade-off and learning model is* quite simplistic, it does illustrate that diverting a small amount of attentional resources can be expected to produce small but statistically

dete. able recognition performance changes.

<u>Strategy and automatic frequency encoding</u>. The differences between the Look, Graphic, and Semantic/Intentional conditions conflict with the Hasher and Zacks (1979) proposal that frequency encoding of attended words is insensitive to subject strategies. Our subjects in the semantic search conditions (i.e., Intentional Learning and Semantic Orienting) showed significantly better performance than those in the Graphic search condition, which in turn showed better performance than those who performed the digit search (i.e., Ignore and Look condition). The extremely poor memory performance for the digit search subjects can be interpreted as the result of not satisfying the criterion that the words be "attended" to. However, that argument does not hold for both the semantic and graphic search conditions. The targets in those conditions were accurately detected (and would be expected to satisfy the "attended" criterion). The differential encoding strategies resulted in differential frequency estimation performances.

What might be the explanation of the finding indicating a lack of strategy effects reported by Hasher and Zacks (1979; Zacks, Hasher & Sanft, 1982)? There are many procedural differences between our experiment and theirs. The most salient (and important) difference is that we used a much greater range of strategies than they. The Hasher and Zacks (1979, p. 371) strategy manipulation typically contrasts performance of subjects who are informed about a later frequency judgment task with subjects who are not. However, both groups are told "after you see the list, your memory will be tested." Hence, the strategy manipulation is *limited to explicit knowledge of the upcoming frequency test.* In our experiment we also found no significant difference between our Intentional frequency Learning and Semantic Orienting condition subjects. However, we did find significantly poorer performance when Graphic Orienting and digit search strategies were used. A second major difference is that we presented words for only .6 sec whereas Hasher and Zacks present words for 2 to 4 sec. We also presented a much wider range of frequency variability across words (range 0 - 20 repetitions vs. 0 - 4, Hasher & Zacks, 1979).

We interpret the lack of differences observed by Hasher and Zacks as being due to frequency encoding showing an early asymptote and little benefit from extended periods of controlled processing. We assume that LTM storage for word frequency reaches asymptote in the first few seconds of semantic processing. Hence, we suggest that what Hasher and Zacks refers to as "Automatic encoding" be interpreted as early asymptotic controlled process encoding of event frequency.

It is important to note that the above discussion reinterprets rather than reduces the importance of the "automatic frequency encoding" concept. It is important to demonstrate, as Hasher and Zacks have, that certain types of memory modification should show an early asymptote and be relatively insensitive to depression, high arousal, individual differences, and aging.

<u>LTM storage as a function of amount and type of controlled processing</u>. The present results are consistent with the hypothesis that LTM storage varies with the amount and type of controlled processing. In the Ignore condition where

words received little, if any, controlled processing, there was no evidence of LTM storage. Words would be expected to receive more controlled processing when shifting from the Ignore, to Look, to word search conditions (i.e., Graphic, Semantic, and Intentional). As hypothesized, performance increased across these conditions.

Experiment 2

Automatic/controlled processing theory predicts that LTM storage cannot occur without controlled processing and that accurate automatic processing can *occur without LTM storage. Experiment 1 showed* that LTM storage was a function of the type and amount of controlled processing. In the present experiment we examined whether there is any LTM storage after automatic processing. We trained subjects to categorize words via automatic processing while controlled processing resources were used to perform a primary task. Then we tested frequency estimation performance and recognition memory for the previously categorized words. Our hypothesis was that if semantic categorization is automatic, then subjects would learn nothing about the distractors (i.e., words from the non-target categories). We predicted that if the semantic search, which showed excellent frequency judgment performance in Experiment 1 (controlled processing, Figure 3 circles), was performed only by an automatic process, subjects would show neither an ability to estimate word frequency, nor to recognize the presented words.

In order to develop an *ability* to automatically categorize words, subjects must receive extensive training at *consistently* categorizing words. Fisk and *Schneider (in press) have shown* that subjects who practice categorizing words that are consistently mapped develop an automatic processing detection ability for the trained words. A consistently mapped category is one in which all the words in the category are attended to and never ignored. For example, if a subject pushes a button every time he/she sees a vehicle word, and never ignores the vehicle word, the category of vehicles is consistently mapped. Typically, after extensive consistently mapped training (e.g., 2000 trials) the automatic categorization process is well developed. The reader should note that an automatic process does not simply result from practice at searching for the category. If the words are variably mapped (e.g., a word can be a target on one trial and a distractor on the next), there is little performance improvement with practice (see Fisk & Schneider, in press; Schneider & Fisk, Note 1).

Fisk and Schneider (in press) have claimed to develop automatic semantic categorization based on their data showing four characteristics associated with automatic processing. They found that CM trained category search showed: 1) *substantial improvements with practice;* 2) no significant effect of increasing the number of categories to search for; 3) no decrement in automatic detection accuracy when subjects are required to perform a simultaneous controlled processing task; and 4) interfering effects of automatic targets on a simultaneous controlled processing task. Note the last three effects were found only for very well practiced automatic category search.

Our objective is to show that words which are processed at least to a level at which a semantic judgment is needed do not result in LTM storage. It is critical to demonstrate that the search is performed at the category rather than a feature level. With 2000 search trials needed in order to develop an automatic search, it is conceivable that subjects learned to detect the visual feature patterns of individual words and did not semantically process the words. Schneider and Fisk (Note 1) have presented evidence that there is substantial semantic category level processing in automatic category search. They found: 1) learning rate was independent of the number of trained members of the category; 2) there was high positive transfer (72 - 92%) to untrained members of the category; and 3) words which caused false alarms showed a strong semantic relationship to the trained categories. These results suggest automatic category search is semantically based.

The present experiment sought to measure LTM storage resulting from pure automatic processing of words processed to the semantic level. Since automatic and controlled processing frequently co-occur in the processing of a specific stimulus (see Schneider, Dumais & Shiffrin, in press), an experimental test of pure automatic processing requires very careful experimental control of the subjects' processing of each word. Shiffrin and Schneider (1977, pp. 162-165) assumed that a letter string can be processed to the feature, character, word, and category level by automatic processing. At any given level of processing, a node activated by an automatic process may cause an automatic attention response. This attention response causes controlled processing to be allocated to the stimulus producing the automatic attention responses (see Schneider & Shiffrin, 1977, Experiments 3 a, b, c, Shiffrin & Schneider, 1977, Experiments 1, 3, 4d). We propose that due to the occurrence of an automatic attention response, the automatically processed target word and possibly one or two words following the target would be processed with controlled processing resources. *In the present experiment, we examined recognition memory for target words,* "buffer" distractor words (*i.e.,* words which immediately follow the target words), and other distractor words. Only the processing of distractor words, referred to as test distractors, is expected to reflect automatic processing.

To ensure that distractor words are not controlled processed, such resources must be consumed by another task while a subject concurrently performs the category search task. The fact that distractor words are automatically processed to the semantic level, does not prohibit a subject from also controlled processing the same word. In the present experiment subjects were required to perform a digit search task in addition to a category search task. The digit search task was made sufficiently difficult to require total allocation of controlled processing resources for maximal accuracy (i.e., resource limited). Only when subjects maintain maximal digit search performance, can it be assumed that distractor words are processed by purely automatic processing. Any drop from the subjects' peak digit search performance might be allocated to control processing of the words. In addition, since it may take a short period of time (e.g., 1 sec) for the control process to be fully consuming resources, the first two words presented on each trial were start buffers. Some recognition of the buffer words is expected.

Experiment 2 combined the Semantic Orienting task and the Ignore digit search task in Experiment 1. The subjects were required to respond to the occurrence of exemplars from a specified semantic category in addition to

performing a concurrent controlled processing digit search task. The digit detection task was the primary task and the category detection task was secondary. The subjects were strongly encouraged to protect their *primary* task performance; that is, to maintain dual task digit search performance equivalent to their single task digit performance level. Subjects were also trained to develop an automatic process to a specified semantic category. In addition during pretraining, subjects' ability to detect novel targets (i.e., untrained vehicle words) was assessed in order to verify that the search was semantically based.

Method

Subjects. Eight University of Illinois students were paid for their participation. *All subjects reported English as their native language* and normal or corrected-to-normal vision.

Search task. The displays used in this experiment were the same as Experiment 1, except the words were from three to six letters in length. Subjects performed a digit detection task concurrently with a category detection task. The digit detection task, which was the *primary* task, was the same as the task performed by subjects in the Ignore and Look conditions of Experiment 1 (see Figures 1 and 2). The category task required subjects to detect exemplars from the category of vehicles. The digit task and category task were performed as single tasks and in dual task conditions. In all the dual task conditions, subjects were *instructed to maintain their digit search performance* even if it resulted in a substantial decline in category search detection.

On each dual task trial, the subjects were presented their average percent digit detection accuracy. This accuracy feedback was displayed for one second. Next, the memory set (two digits and the target category label) was displayed *until the subject pushed* the initiation button. Thereafter, a central fixation dot was displayed for 500 msec. Then two frames (400 msec each) of X's and Y's in all display locations were presented to facilitate proper fixation. The actual trial frame sequence consisted of four characters (two digits and two random dot patterns) positioned to form a square around a centrally displayed word. The digits were first presented on one diagonal of the square then the other, alternating on a frame by *frame basis. The same word was displayed on* two successive frames (display time of 800 msec). A response within two sec after a category or digit target was considered a "hit". During the last two sec of the display sequence, six X's were displayed in the word display location to mask out the last word. The subjects' task was to push a button corresponding to the display location of a target digit and to push a single button upon detection of a target category exemplar. There were 0, 1, or 2 targets during a trial.

Prior training. It is important to note that subjects had had extensive dual task training prior to participating in the memory test portion of the experiment. This training, from 10 to 15 hours, was required for subjects to develop the ability to maintain (or protect) their primary task digit performance. Subjects received four hours (approximately 3,000 trials) of single frame reaction time training in a word classification task. In that task, subjects indicated whether or not words were from the category of vehicles. Then dual task training was given in which subjects performed both *single* and dual task *digit* search and word search. The digit search task was equivalent to the Ignore condition and the category search was equivalent to the Semantic condition in Experiment 1 (see Figure 1, also below). During dual task training, the subjects developed the ability to automatically detect the vehicle category exemplars without reducing performance on their digit search task. Subjects had had approximately 1,168 trials of single task category and single task *digit* search training *and approximately 1,328 trials of dual task search* training during eight sessions. (One subject required five extra sessions (700 dual task trials) before she could perform the dual task without deficit to either category or digit search.) For details of the experimental procedures used in pretraining see Schneider and Fisk, Note 1.

Target and distractor word switch. On the second to last dual task session (i.e., session 9 for seven subjects and session 14 for one, see prior training) new distractor words and target category exemplars were presented. During training (sessions 1-8), targets were sampled from eight words from the vehicle category. On session 9, three new vehicle words could occur as well as the six previously trained vehicle words. In addition, new distractor words were used on session 9. These changes allow assessment of whether the search was category based or not. On this session only dual task conditions were run.

Memory test session. Subjects believed the "memory modification" session was part of the dual task experiment they had been participating in for the past *nine sessions. Subjects spent 20 minutes searching for words from the vehicle* category while concurrently performing the digit task. The distractor words were switched a second time during the first phase of the experiment (dual task session 10A). None of the words used in this phase were from categories used as distractors in the second phase (the test of memory modification phase, session 10B). Following the first 20 minutes, the subject's name appeared on his/her screen. The distractors then used in session 10B were the *critical* words used for the test of memory modification. There were a total of 370 word displays during the critical memory test portion of this experiment. The total word displays consisted of: A) four distractor words each presented 20 times; B) eight distractor words each presented 10 times; C) sixteen distractor words each presented five times; D) twenty distractor words each presented one time; E) twelve occurrences of words from the target (vehicle) category (each target word was presented two times); and F) three types of "buffer" displays. These "buffer" displays consisted of the first two words presented at the beginning of each trial (referred to as beginning buffer words) and the first and second word immediately following each occurrence of a target category exemplar (referred to *as buffer 1 and buffer 2, respectively*). There were three Buffer 1 and three Buffer 2 words (each presented four times) and there were five beginning buffer words (presented on the average 14.8 times). The series of 370 word displays were broken up into 37 "trials". Before each trial, the subject was presented his/her digit detection accuracy for 1 sec. All subjects completed the 37 trials in approximately 10 minutes. Following the dual task search, subjects were given a two-minute math task, *a frequency estimation task, and a forced* choice recognition test. The frequency estimation task was conducted in the same manner as in Experiment 1. All words displayed during the last 37 trials

(i.e., target vehicle names, buffer words, and distractor words) were presented on a sheet of paper with an equal number (65) of words never used during the experiment (or during training). The recognition task consisted of 65 cards each containing two words. One word on each card had occurred during the second phase search task. The subjects sorted the cards into piles corresponding to their choice of the correct word. Subjects went through the stack of cards once at their own pace.

Materials. All words were chosen from the category norms of Battig and Montague (1969). The search task distractor and buffer words were paired (on the forced-choice recognition cards) with words from a non-overlapping category (Collen, Wickens, and Daniele, 1975). The vehicle words that occurred as targets during the search task were also tested. In this case, the words used as foils were members of the target category and had occurred previously during the prior training.

Results

Training target detection data. The mean hit rates for the digit and word detection tasks are presented in Table 2. The false alarm rates were low, averaging less than 3% after session 4.

The training data (sessions 1 - 8) show significant effects of sessions ($p < .05$) in all conditions. The single task digit search performance peaked on session 4 at .898 and then declined. Dual task digit search improved with practice approaching the single task level by session 8.

Insert Table 2 about here

Dual task category search improved across sessions to .90. However the dual task performance was below the single task level (though not significantly, 9% decrement, $t(7) = .71$, $p = .07$ one-tailed). The high performance in the dual task category detection with little decrement in the digit task performance is indicative of a fairly well developed automatic category search process (see Fisk & Schneider, in press; Schneider & Fisk, Note 1).

Switching distractors and targets during search. The switching of distractors on sessions 9 and 10A resulted in small improvements in category detection performance from that in session 8. Switching distractors on session 10B resulted in a significant reduction in category detection probability (.18 decline from session 10A, $t(7) = 6.07$, $p < .001$) though not significantly different from session 8.

Subjects showed substantial detection of new target words from the trained category. Through session 8, subjects had been searching for six vehicle words. On session 9, three new vehicle words were added to the target set. Subjects were not informed that these new words would appear. Subjects detected 72% of the new target words and they detected the majority of the words on the first presentation. In general, subjects were surprised by the first occurrence of

the new words but responded correctly. The subjects' detection of new targets was significantly below the detection of trained targets ($t(7) = 4.40$, $p < .01$). Relative to the detection of old targets, the new targets showed a 75% transfer rate, replicating other category search transfer studies (Schneider & Fisk, Note 1).

The high performance transfer when both targets and distractors were switched indicates that subjects were performing a semantically based search. The ability to detect new words presented the first time indicates that the words are still being semantically processed even after eight hours of dual task category search.

Word frequency estimation. Table 3 presents the word frequency estimation and recognition accuracy. With the exception of target words, subjects had little if any ability to estimate the frequency of words. The median frequency for all conditions was 0, except for target words which were accurately estimated at a median frequency of 2. The mean frequency results suggest that the presented words averaged a higher frequency estimate than foils, but there was no differential frequency information. The correlation between subjects' estimated frequency and actual presentation frequency was .14 which was nonsignificant.

Frequency based recognition accuracy. The recognition data indicates that subjects' recognition of distractors was small but statistically demonstrable. As in Experiment 1, we scored the data treating all frequency estimates of greater than 0 as a hit or false alarm and 0 estimates as misses or correct rejections. Then we tested to see if the hit rate was greater than the false alarm rate in each condition. We also calculated the accuracy score corrected for guessing [(Hit - False Alarm)/(1 - False Alarm)].

Subjects had good recognition of target words (.69) and some recognition of beginning buffers (.26). The distractor words following the target words (i.e., Buffer 1) were detected only somewhat better than other distractors. The second buffer word following the target words (i.e., Buffer 2) was detected at the level of the test distractors.

The overall recognition accuracy for the test distractors was low (.17) but significant ($t(7) = 3.82$, $p < .001$). Of the 48 words categorized over a total of 260 presentations of .8 sec each, subjects averaged a recognition of 8 words. Recognition performance improved little with increased repetitions.

Forced choice recognition accuracy. The forced choice data show a pattern consistent with the frequency based recognition data. The d' index of sensitivity was estimated from the two-alternative forced-choice distribution (see Hacker & Ratcliff, 1979). The target words and beginning buffer words showed substantial recognition performance (d' = 1.74 and 1.55 respectively). Some subjects showed good recognition of the words immediately following the target words (Buffer 1 average d' = .81). The second buffer recognition was at the level of the test distractors.

The overall forced-choice recognition accuracy of the test distractors was low (.55 where chance = .50; d' = .19) but significant ($t(7) = 2.38$, $p < .025$ one-tailed for d'). There was little improvement in recognition performance with increasing repetitions.

Discussion

In contrast to Experiment 1, Experiment 2 shows evidence of very little LTM storage resulting from semantic categorization. In both experiments, subjects responded to vehicle names. In Experiment 1 the task was novel and presumed to represent a controlled process search. In Experiment 2 the task was well practiced and presumed to represent primarily an automatic process search. In addition, in Experiment 2 subjects concurrently performed a variably mapped digit search task in order to consume control processing resources. The ability of subjects in Experiment 2 to detect new target words from the trained categories indicates that the search required semantic evaluation of the presented words.

Every measure of LTM storage shows substantial storage during controlled process search (Experiment 1) and little from automatic process search (Experiment 2). It should be noted that this occurs even though words were presented for 33% longer durations on Experiment 2 (i.e., 800 msec) than Experiment 1 (i.e., 600 msec). Comparing Experiment 1 and 2 performance for distractors presented 20 times the median frequency estimates were 18.6 and 0, recognition accuracy of .98 and .17, and d' of 3.58 and .19. A distractor semantically searched once in Experiment 1 showed substantial recognition (.37), whereas in Experiment 2 it did not (.07). Frequency estimation after semantic search was substantial for Experiment 1 (correlation .63), but not in Experiment 2 (correlation .14).

The distractor learning in Experiment 2 shows a pattern of results similar to the Look condition of Experiment 1. In the Look condition subjects performed the digit task and were told to try to learn the words. The average distractor learning for the Look condition was .11 and in Experiment 2 it was .17.

The small but statistically demonstrable learning in Experiment 2 is incompatible with the hypothesis that pure automatic processing does not modify LTM. A critical issue is whether subjects allocated any controlled processing resources to the words. It should be noted that by the end of Experiment 2 subjects had had 15 hours of practice at performing very boring search and detection tasks. One subject commented that she occasionally looked at the distractors to see what word categories were present while performing the digit search. It is likely that subjects did not put in their maximal effort during the digit search.

Assuming subjects allocated some controlled processing resources to the words, how much would they have to allocate to obtain the observed recognition performance? To estimate the required allocation we can use the same model used in Experiment 1 (see Appendix). The predicted values are probably an underestimate since the words were presented 33% longer in Experiment 2. Using these procedures the observed .17 recognition performance would be predicted if

subjects allocated 11% of their resources to the semantic processing of the words.

Examining the single and dual task data we can make a lower bound estimate of the amount of resources not used in the digit search. Any estimate embodies many assumptions (see Navon & Gopher, 1979). What one wishes to do is compare the observed dual task digit detection for each subject with that subject's maximal single task digit performance. We need to assess single task performance when the subject is allocating all the available resources to the digit task. But when are subjects allocating all the available resources? If we use the performance on pretraining session 8 (the last session with both single and dual task measures), subjects' dual task digit accuracy (.78) was 91% of the subjects' single task digit detection accuracy (.86), suggesting a 9% time sharing. Our subjects' single task performance peaked on the fourth session, suggesting the session 8 performance might be a low estimate of single task performance capabilities. When subjects were asked about the performance drop after session 4, some subjects commented that they worked hard until they felt they mastered the task and then probably got bored. The single task digit hit rate was .898 +/- .020 on session 4. In previous VM digit search conditions similar to the present experiment, we have observed a 10% vigilance fluctuation (Schneider & Fisk, Note 1) suggesting that the single task performance level represents less than total resource allocation to the primary task. In any case, the 9% sharing observed in session 8 is within the range of the 11% sharing which would be predicted to yield the observed detection accuracy.

We do <u>not</u> claim that the observed recognition level is accounted for by the subjects' time-sharing, but only that it could be. All the observed dual task differences and the observed recognition levels are at or near the noise level. There are many assumptions both in calculating the resource allocation and expected learning rate. The present effort does illustrate that the observed low but reliable recognition performance is in the range expected under reasonable assumptions about subjects' time-sharing.

It should be noted that expecting a zero recognition level may be a somewhat inappropriate criterion. Some words will attract attention and be processed just as the target words. Several experiments suggest that subjects detect their own name in an unattended channel (e.g., Wolford & Morrison, 1980; Moray, 1959). We found during pilot testing that certain words (e.g., "Rape" and "Murder") are detected by almost all subjects even if they are engaged in a heavy work load task (e.g., the Ignore condition of Experiment 1). Running a separate control condition to assess learning without automatic processing might provide a better criterion of the expected learning. In the present experiment such a control would have provided subjects fifteen hours of practice at digit search only. Then subjects' memory for the distractor words could be compared with that shown by subjects who were performing an automatic search through the distractors while performing the digit search.

The Experiment 2 results can be interpreted in two ways: Either 1) automatic semantic processing resulted in small but statistically reliable LTM storage; or 2) automatic search resulted in no LTM storage but subjects did allocate some control processing resources to the words. To resolve these

interpretations additional methodological improvements must be made and additional research carried out. We feel that the trend across studies favors the second alternative. As experimental control of subjects' attention improves, subjects' recognition approaches zero even with very sensitive measures.

The results allow a conclusion that there is little if any recognition memory for categorizing words through fairly pure automatic processing. Words presented twenty times and correctly classified as not being a member of a semantic category were recognized only slightly above chance (recognition two choice accuracy of .54).

General Discussion

The present results suggest that LTM modification and controlled processing are closely linked, but accurate automatic performance can occur with little or no LTM storage. In the Graphic search condition of Experiment 1, subjects processed a word to the orthographic level once for .6 seconds in a sequence of 360 word displays, then performed a two-minute math task, and still showed significant recognition accuracy for the word. Hence, a small period of controlled processing in a task requiring primarily letter search changes LTM. As the nature (e.g., shifting from Graphic to Semantic Orienting) or the amount of the controlled processing changes, the amount of learning changes. We assume that the more task appropriate the controlled processing is, the better the performance on a given memory test. If subjects' controlled processing resources are consumed in a primary task, such as the Ignore condition (Experiment 1), there is no evidence of any LTM storage even with very sensitive measures. The data from the Look condition suggest that if subjects allocate small quantities (not statistically significant) of control processing resources to word encoding, small but significant recognition memory will result. The above results suggest controlled processing and memory modification are tightly coupled.

Data from Experiment 2 suggest that for automatic processing there is little if any linkage between performance and memory modification. Experiment 2 showed that subjects could categorize words accurately via automatic processing with little if any memory modification for distractors.

The poor learning in the automatic semantic search in Experiment 2 is in sharp contrast to the substantial learning during control processed semantic search in Experiment 1. The small (but statistically greater than zero) recognition memory observed in Experiment 2 can be interpreted in two ways. Either subjects allocated some control processing resources (e.g., 11$) to the word search task or automatic search results in small amounts of LTM storage. The evidence that some subjects were control processing some of the words (e.g., verbal reports and less than maximal digit search performance), the very poor recognition performance and the methodological difficulties of assessing pure automatic search, lead the present authors to speculate that an assessment of pure automatic processing would show no evidence of LTM storage.

The lack of memory for complex automatic behaviors is common in daily life. Reason (1979) provides examples from reports of subjects forgetting in daily life. One subject reported, "as I was leaving the bathroom this morning, it suddenly struck me that I couldn't remember whether or not I had shaved. I had to feel my chin to establish that I had". Such reports suggest over-practiced common activities, performed while control processing resources are engaged in other tasks, result in little, if any, LTM storage.

The present experiments illustrate the need for substantial methodological care in attempting to assess relatively pure automatic and controlled processing. Attempts to assess the learning that results from words presented in an "unattended" channel should: 1) provide evidence as to how well the words actually are processed; 2) provide evidence as to the sensitivity of the memory test; 3) provide subjects a good "cover story"; 4) require subjects to perform a highly demanding controlled processing task as a primary task; and 5) test for material presented after the first few minutes of presentation (during which subjects are learning to allocate attention to the specified "attended" task).

Laboratory procedures that assess memory modification during automatic processing must be carefully designed. First, the automatic process must be very well practiced (e.g., 2,000 training trials). Controlled processing resources must be occupied by requiring concurrent performance of a resource limited primary task. Subjects must be induced to devote full processing capacity to the controlled processing task. In search experiments, the critical test of learning must examine memory for distractor words. Buffer words should be presented after targets so that post-target controlled processing is eliminated. In addition, buffer trials should be presented prior to the memory test portion of the experiment and the learning portion should begin without any indication to the subject that the task has been significantly altered.

The results suggest a connection between the memory modification and attentional phenomena. Controlled processing is characterized as effortful, slow, serial, and capacity limited, and which can perform novel or poorly developed processing operations. One can interpret the allocation of controlled processing as increasing the activation of a node in memory. As the activation of a node increases, there is greater partial activation of elements connected to the node. This partial activation interferes with performing other tasks which use the same sections of memory, thus causing an apparent serial capacity limited processing performance. However, the greater activation of elements also results in greater memory modification, thus showing better long-term memory recognition and recall performance. In contrast, automatic processing is characterized as fast, parallel, effortless processing that is not limited by short-term memory capacity. Automatic processing can be interpreted as developing strong links between a small set of nodes. Even the weak activation of one node results in activating a long sequence of nodes enabling accurate performance. Although the processing sequence may be long, there are few elements activated in any one region. Therefore, other tasks can operate well in the same sections of memory, thus, processing appears parallel. However, weakly activating a node activates only a few elements and the links to these elements might already be maximally developed. Hence, there would be little or no measurable long-term memory modification. Should a subject decide to

allocate controlled processing resources to an automatic task, the subject partially activates many elements in memory plus the well developed automatic processing chain. Performance exhibits the speed associated with automatic processing but the capacity limitations associated with controlled processing (see Schneider & Fisk, 1982, Experiment 2b). The subject would also exhibit the memory modification associated with controlled processing. The close parallel between the attention and memory literature suggests when we process information we can perform serial controlled processing in a stage and remember, or parallel automatic processing in a stage and forget.

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Footnotes

[1]Kellogg assessed multiplication performance in an effort to determine whether subjects divided resources. However, the multiplication performance did not decline even when subjects were explicitly told "to attend to the faces if possible" (Kellogg, p. 383). This suggests that the multiplication measure is insensitive at least to short periods of reduced attending or different resource pools.

[2]In addition to problems in dual task measurement sensitivity, large within and between subject variability make it unlikely that decrements in the 1% range could be detected. If variability between blocks within subjects is in the range of 5%, it would be unlikely that short shifts of attention can be detected.

[3]The present estimation procedure assumes that the probability of learning a word which is presented once increases linearly as a function of the percent of resources allocated to it. However, in general, the marginal utility of additional resources decreases as more resources are added (see Navon & Gopher, 1979). One would expect that processing benefits more from allocating the first 10% of available resources to a task than the last. The present method estimates the the average utility which may represent a substantial underestimation of the marginal utility for small quantities of resources. The present approach also assumes an undifferentiated resource model of attention (Kahneman, 1973). If attentional resources are somewhat differentiated (see Wickens, 1980) then there may be resources available to word encoding which are not used in the digit search task. This would suggest that effective resources available for word encoding would be greater then those removed from the search task. The estimation also assumes that the single task performance represents maximal resource allocation to the primary task. If subjects expend less than full effort on the primary task, the present procedures would underestimate resources available for the encoding task.

[4]Assuming some fall off in marginal utility of resources, the expected digit resource utilization would be less in the Look condition.

[5]We interpret the fall off in category detection between the search for 10B distractors and the other sessions to be due to greater semantic confusability of the distractors used during 10B. Since there were over fifty words in each set, it is unlikely that the average physical similarity of sets varied.

Appendix

Recognition accuracy as a function of time sharing

The present model provides an estimate of the expected recognition performance as a function of the proportion of the words which are control processed. Recognition performance as a function of the number of word repetitions is fit by a logarithmic function

$$F(j) = a + b \ln j \qquad (1)$$

when 'F(j)' is the corrected probability of recognition, 'a' is the base recognition for one presentation, 'b' is the increase of recognition as a function of additional repetitions, and 'j' is the number of repetitions. For the Semantic and Intentional conditions of Experiment 1, a = .37, b = .20, and the correlation between the observed and fitted recognition scores was .976. For the Graphic conditions, a = .25 and b = .14, and the correlation was .996. Equation 1 provides a reasonable fit to the observed data. We use it to estimate recognition as a function of repetitions between 1 and 5.

We assume that the number of words that a subjects will control process is directly proportional to the proportion of resources allocated to word processing and that F(j) holds for all the processed words. Thus the expected recognition performance given a certain proportion of time sharing is:

$$M(i) = \sum_{j=1}^{R(i)} \binom{R(i)}{j} T^{j} (1-T)^{(R(i)-j)} F(j) \qquad (2)$$

where 'M(i)' is the expected recognition performance of word 'i', 'R(i)' is the number of repetitions of the word 'i' presented in the experiment, 'T' is the proportion of time sharing, and 'F(j)' is from equation 1.

In estimating T for the Look condition of Experiment 1 and the recognition performance of Experiment 2 we allowed T to increase until the estimated average recognition performance matched the observed recognition. For T in the range of .10 or less, estimated recognition performance is determined primarily by the recognition performance following presentation. Therefore the estimated time sharing performance is fairly insensitive to using different equations for F(j) as long as F(1) is equal to the observed recognition performance.

Table 1

Experiment 1 Word Recognition Accuracy of Distractors

	Hits					False Alarms
Frequency	1	5	10	20	ALL	0
IGNORE	.085 (-.027)	.078 (-.030)	.153+ (.068)	.145 (.047)	.103 (-.002)	.099
LOOK	.374 (-.013)	.442+ (.138)	.465* (.225)	.463+ (.163)	.428** (.113)	.325
GRAPHIC	.460** (.236)	.658** (.497)	.700** (.563)	.720** (.611)	.612** (.440)	.309
SEMANTIC[a]	.498** (.342)	.824** (.785)	.853** (.799)	.981** (.973)	.742** (.665)	.229
INTENTIONAL	.586** (.363)	.835** (.753)	.854** (.758)	1.00** (1.00)	.776** (.654)	.342

The numbers in parentheses represent the average hit rate after within subject corrections for guessing. Corrected Hits = (Hits - False alarms)/(1 - False alarms)

\+ Significantly greater hits than false alarms by a paired comparison *t*-test, $p < .05$, one-tailed uncorrected for multiple *t*-tests, $p < .23$ if corrected for multiple *t*-tests.

* $p < .01$ one-tailed uncorrected for multiple *t*-tests, $p < .05$ corrected.

** $p < .001$ one-tailed uncorrected, $p < .005$ corrected.

a Excludes 1 subject who estimated a word frequency of at least 1 for all words resulting in a 1.0 false alarm rate.

Table 2

Experiment 2 Target Detection Accuracy

	pretraining								Switch 1[a]	Switch 2[b]	Switch 3[c]
Detection session	1	2	3	4	5	6	7	8	9	10A	10B
Digit detection											
Single task	.81	.81	.85	.90	.85	.88	.80	.86			
Dual task	.58	.66	.68	.68	.68	.80	.80	.78	.79	.82	.83
Category search detection											
Single task	.93	.96	.99	.95	.99	1.00	.99	.99			
Dual task	.62	.74	.76	.76	.76	.83	.91	.90	.96	.98	.80
Dual task (untrained)									.72		

a -- on this session the distractor words were switched and new (untrained) vehicle target words were added without the subjects' knowledge

b -- new distractor words were switched a second time

c -- new distractor words were switched a third time. The memory test was performed on these distractors.

Table 3

Experiment 2 Word Frequency Estimation and Recognition

	Hits								False Alarms	
	Start Buffer	Targets	Buffer 1	Buffer 2	Test Distractors					Foils
Presentation Frequency	14.8	2	4	4	1	5	10	20	Total	0
Median Freq est	0	2	0	0	0	0	0	0	0	0
Mean Freq est	2	3.9	1.4	1.2	.5	1.2	1.5	1.3	1.0	.1
Hit/ False alarms[a]	.270*	.697**	.165^{+}	.289^{+}	.119^{+}	.144^{+}	.234*	.188*	.189*	.029
Accuracy	.256	.687	.140	.265	.091	.121	.216	.167	.169	
Forced choice recognition accuracy	.75	.85	.62	.54	.49	.56	.55	.56	.55	
Recognition d'[b]	1.55**	1.74**	.81	.14	.17	.11^{+}	.17	.24	.19^{+}	

a -- matched pair *t*-tests of hits relative to false alarms,
frequency estimate above zero is considered a hit if false alarm.
b -- *t*-tests relative to zero

+ -- one-tailed *t*-test significant at *p* <.05 uncorrected for multiple tests
* -- one-tailed *t*-test *p* < .01 uncorrected for multiple tests
** -- one-tailed *t*-test *p* <. 001 uncorrected for multiple tests.

	TARGET	DISTRACTOR
INTENTIONAL (Vehicle Search & Remember Words)	5 # CAR # 7	6 # HAT # 2
SEMANTIC (Vehicle Search)	5 # CAR # 7	6 # HAT # 2
GRAPHIC ('G' Search)	5 # GET # 7	6 # HAT # 2
LOOK (3 or 5 Search Remember Words)	5 # CAR # 7	6 # HAT # 2
IGNORE (3 or 5 Search Ignore Words)	5 # CAR # 7	6 # HAT # 2

Figure 1. Experiment 1 search conditions and displays

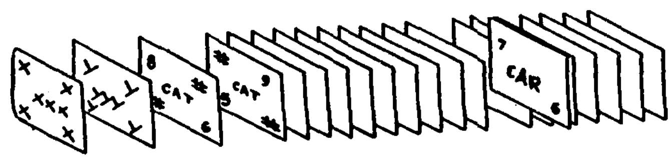

Figure 2. Representation of the word display sequence for all conditions. For the Look and Ignore conditions the 2 digit memory set was presented just before every trial.

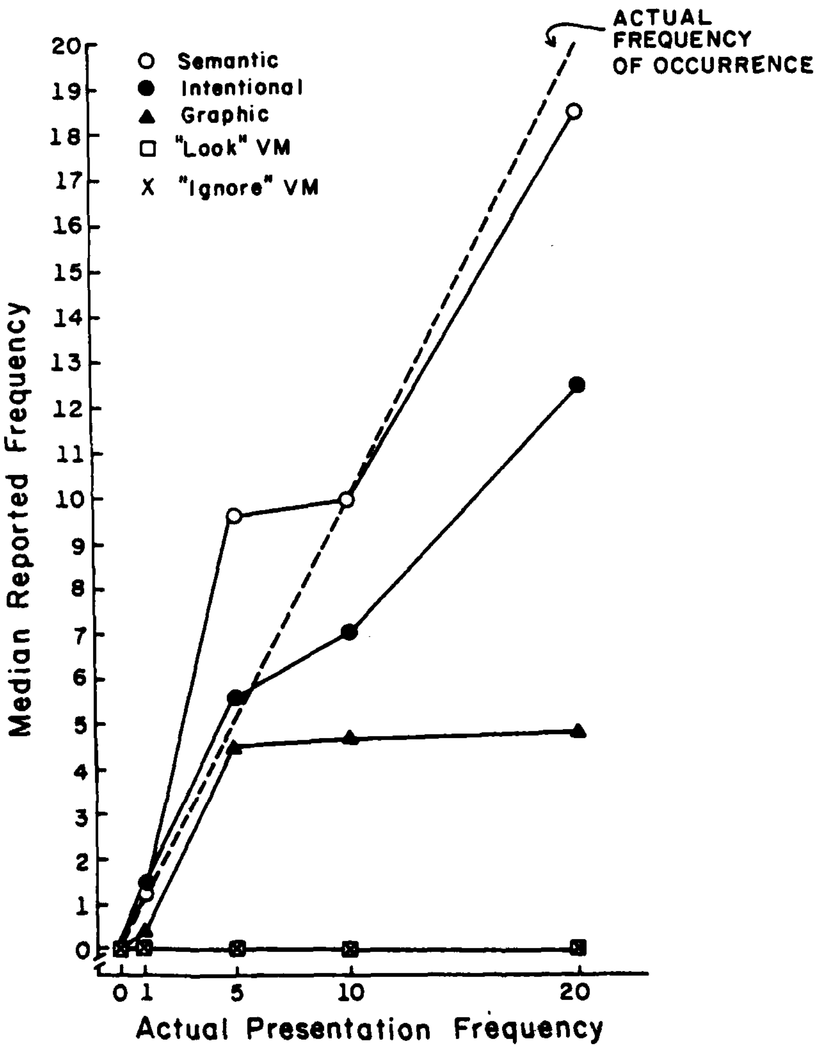

Figure 3. Experiment 1 estimated frequency data.

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